CHAPTER 4 - ENVIRONMENTAL RADIOLOGICAL PROGRAM INFORMATION

Radionuclides present in the environment, whether naturally-occurring or human-made, contribute to radiation doses to humans. Therefore, environmental monitoring around nuclear facilities is imperative to characterize radiological conditions, detect releases, and determine their effects, should they occur. Because of this, the DOE requires an environmental monitoring program for nuclear facilities (DOE Order 5400.1).

The WIPP Environmental Monitoring Program monitors air, surface and groundwater, soils, and biota to characterize the radiation environment and to detect potential releases from WIPP activities. This program is carried out in accordance with the EMP. This chapter summarizes the results of radiological monitoring during CY 2001.

The radiological environment near WIPP includes natural radioactivity, global fallout and, potentially, radioactive contamination from the Project Gnome. A nuclear device was detonated underground in bedded salt on December 10, 1961. The test site for Project Gnome was located about 20 km (13 miles) southwest of the WIPP site. The Project Gnome shot vented into the drift and up the shaft to the atmosphere. Therefore, most environmental samples are expected to contain small amounts of natural radioactivity and fission products.

Throughout this chapter, radionuclides were considered "detected" in a sample if the measured concentration or activity minus 2 x total propagated uncertainty (TPU) exceeded the minimum detectable concentration (MDC). The MDC was determined by the different analytical laboratories based on the natural background radiation, the analytical technique, and inherent characteristics of the analytical equipment. The MDC represents the minimum concentration of a radionuclide detectable in a given sample using the given equipment and techniques.

Total propagated uncertainty is an estimate of the uncertainty in the measurement due to all sources, including counting error, measurement error, chemical recovery error, detector efficiency, randomness of radioactive decay and any other sources of uncertainty.

Comparisons of radionuclide concentrations were made between years and locations using the statistical procedure, ANOVA. When this, or another statistical test, was used, the value of p, the probability of obtaining the value of the test statistic by chance alone, was reported. In many cases, scientists have accepted a value of $p < 0.05$ as indicative of a difference between samples. However, interpretation of p requires some judgment on the part of the reader; individual readers may choose to defend higher or lower values of p as their cutoff value. For this report, $p < 0.05$ was used.

4.1 Effluent Monitoring

If radionuclides are released into the environment from WIPP, they would first be detected in airborne effluents. Thus, WIPP monitors airborne effluents at three locations, effluent monitoring Stations A, B, and C. Station A samples the unfiltered

underground exhaust air. Station B samples the underground exhaust air after HEPA filtration and, sometimes, nonfiltered air during maintenance. Station C samples the air from the Waste Handling Building after HEPA filtration. Each station employs one or more fixed air samplers, collecting particulates from effluent air stream and a Versapore filter.

During 2001, 411 samples were collected from Station A for a total air volume sampled of 26,697.5 m^3 (942,707 ft^3). Because only a small fraction of the air released through Station A is sampled, the activity on the filter is normalized to the total air flow through Station A using an EPA-approved methodology. Fifty-six samples were collected from Station B for a total air volume sampled of 29,735.8 m^3 (1,049,994 ft^3), and 53 samples were collected from Station C for a total air volume sampled of 8,312.9 m^3 (293,533 ft^3). Samples were composited each quarter for stations B and C. Because of the large number of samples from Station A, these samples were composited monthly. Samples were analyzed radiochemically for ^{241}Am, ^{238}Pu, and $^{239+240}Pu$, the components of the contact handled waste at WIPP expected to produce 98 percent of the potential dose to humans.

Out of 60 total composite samples, only one sample had detectable radioactivity (Table 4.1). For the remaining 59 samples WIPP Laboratories reported an activity less than the MDC. For the 59 composite samples where there was no activity detected, it was conservatively assumed that the actual activity was equal to the MDC for the WIPP 2001 Annual Periodic Confirmatory Measurement Compliance Report (40 CFR Part 61, Subpart H), and for other effluent reporting requirements.

The sample filter containing the detectable radioactivity, ^{241}Am, was collected from Station A during October 2001 (Table 4.1). In addition, during February 2001 at Station A, and during the third quarter at Station B, the reported activity of ^{241}Am was greater than the MDC. However, in both of these cases, the reported activities were less than two times the TPU, indicating the samples did not likely contained ^{241}Am.

In reference to Table 4.1, the WIPP Laboratories reports the radionuclide results in units of picoCurie/sample (pCi/sample). The laboratory results are converted from pCi/sample to becquerels (Bq). The laboratory results are converted to Bq by multiplying the laboratory results by 0.037.

There was no significant difference in the concentration of any radionuclide at Stations B and C between the years 2000 and 2001. It was not possible to compare results from Station A across years, because the composition frequency changed from quarterly to monthly from year 2000 to year 2001.

Results from Stations A, B, and C were used as input for the dose assessment presented in Chapter 7.

Additional sampling was routinely performed in the underground using fixed air samplers and continuous air monitors. Evaluation of the samples from both indicate there were no detectable releases above background activity from the WIPP facility.

4.2 Airborne Gross Alpha/Beta

Gross alpha and beta measurements in airborne particulates are used as a screening technique to provide timely information on levels of radioactivity in the environment around the WIPP site. Airborne particulate samples were collected from seven different locations around WIPP: Southeast Control (SEC), Carlsbad (CBD), J. C. Mills Ranch (MLR), Smith Ranch (SMR), WIPP East (WEE), WIPP South (WSS), and WIPP Far Field (WFF) (Figure 4.1).

Each week at each station, approximately 600 m^3 (21,200 ft^3) of air was filtered through a 4.7-cm (1.85-in) diameter glass microfiber filter using a low-volume continuous air sampler. The samples were collected at a height of 1.5-2 m (5-6.5 ft) to closely match the height at which air is inhaled by humans. Filters were counted for gross alpha and beta only after being stored for five to seven days in the laboratory to make sure the short-lived radon progeny had decayed.

Blank filters were also counted for gross alpha and beta activities so that background corrections (activities present in the blank filters) could be made in the gross alpha and beta measurements of the air samples. Blanks were counted weekly along with the samples. The gross alpha and beta activities per cubic meter of air were then determined by dividing the total activity of gross alpha and beta found in each weekly sample by the amount of air pulled through each sample. The results are given in Appendix D. The mass and volume of air collected each week are reported in Appendix E.

As expected, weekly gross alpha activity concentrations measured in 2001 varied by an order of magnitude throughout the year at each location (Figure 4.2). Measured concentrations ranged from a minimum of $1.15\times10^{-5} \pm 1.72\times10^{-5}$ Bq/m^3 ($3.11\times10^{-4} \pm 4.65\times10^{-4}$ pCi/m^3) to a maximum of $1.52\times10^{-4} \pm 4.27\times10^{-5}$ Bq/m^3 ($4.11\times10^{-3} \pm 1.15\times10^{-3}$ pCi/m^3) (Table 4.2). However, the annual mean concentrations of gross alpha activities found at all locations were similar, ranging from $5.26\times10^{-5} \pm 3.97\times10^{-5}$ to $6.16\times10^{-5} \pm 5.28\times10^{-5}$ Bq/m^3 ($1.42\times10^{-3} \pm 1.07\times10^{-3}$ to $1.66\times10^{-3} \pm 1.43\times10^{-3}$ pCi/m^3). ANOVA indicated no statistically significant difference between sampling stations ($p = 0.989$).

Table 4.1 - Activity (Bq) of Quarterly Composite Air Samples from Effluent Monitoring Stations A, B, and C

Nuclide	Activity	2 × TPU[a]	MDC[b]	Activity	2 × TPU	MDC	Activity	2 × TPU	MDC
	Station A			Station B			Station C		
				1st Quarter					
^{241}Am				3.11×10^{-4}	7.62×10^{-4}	1.45×10^{-3}	0.00×10^{0}	0.00×10^{0}	5.03×10^{-4}
^{238}Pu		See below [c]		0.00×10^{0}	0.00×10^{0}	1.07×10^{-3}	1.05×10^{-4}	3.65×10^{-4}	7.70×10^{-4}
$^{239+240}Pu$				1.15×10^{-4}	2.31×10^{-4}	3.11×10^{-4}	1.05×10^{-4}	2.10×10^{-4}	2.83×10^{-4}
				2nd Quarter					
^{241}Am				0.00×10^{0}	0.00×10^{0}	5.07×10^{-4}	-3.63×10^{-4}	5.22×10^{-4}	1.69×10^{-3}
^{238}Pu		See below		6.07×10^{-5}	2.11×10^{-4}	4.44×10^{-4}	0.00×10^{0}	0.00×10^{-4}	4.88×10^{-4}
$^{239+240}Pu$				0.00×10^{0}	0.00×10^{0}	1.64×10^{-4}	6.62×10^{-5}	1.33×10^{-4}	1.79×10^{-4}
				3rd Quarter					
^{241}Am				1.21×10^{-3}	1.42×10^{-3}	1.09×10^{-3}	1.10×10^{-4}	6.59×10^{-4}	1.32×10^{-3}
^{238}Pu		See below		-1.09×10^{-4}	2.19×10^{-4}	7.99×10^{-4}	-2.11×10^{-4}	4.26×10^{-4}	1.13×10^{-3}
$^{239+240}Pu$				1.08×10^{-4}	2.18×10^{-4}	2.94×10^{-4}	2.10×10^{-4}	2.99×10^{-4}	2.85×10^{-4}
				4th Quarter					
^{241}Am				0.00×10^{0}	0.00×10^{0}	1.39×10^{-3}	2.18×10^{-4}	4.37×10^{-4}	8.03×10^{-4}
^{238}Pu		See below		0.00×10^{0}	0.00×10^{0}	1.03×10^{-3}	0.00×10^{0}	0.00×10^{0}	7.62×10^{-4}
$^{239+240}Pu$				0.00×10^{0}	0.00×10^{0}	3.77×10^{-4}	2.07×10^{-4}	2.95×10^{-4}	2.81×10^{-4}

			Station A	1st Quarter		Monthly[c]			
	January			February			March		
^{241}Am	5.88×10^{-4}	7.25×10^{-4}	1.08×10^{-3}	6.07×10^{-4}	6.18×10^{-4}	4.11×10^{-4}	0.00×10^{0}	0.00×10^{0}	1.50×10^{-3}
^{238}Pu	1.34×10^{-4}	2.69×10^{-4}	3.61×10^{-4}	0.00×10^{0}	0.00×10^{0}	7.51×10^{-4}	-1.22×10^{-4}	4.26×10^{-4}	1.13×10^{-3}
$^{239+240}Pu$	4.00×10^{-4}	5.99×10^{-4}	9.81×10^{-4}	0.00×10^{0}	0.00×10^{0}	2.76×10^{-4}	0.00×10^{0}	0.00×10^{0}	3.30×10^{-4}
			Station A	2nd Quarter		Monthly			
	April			May			June		
^{241}Am	1.51×10^{-4}	3.02×10^{-4}	5.55×10^{-4}	-3.10×10^{-4}	3.85×10^{-4}	1.02×10^{-3}	6.40×10^{-4}	8.07×10^{-4}	1.28×10^{-3}
^{238}Pu	0.00×10^{0}	0.00×10^{0}	4.33×10^{-4}	-6.07×10^{-5}	1.22×10^{-4}	4.44×10^{-4}	0.00×10^{0}	0.00×10^{0}	4.81×10^{-4}
$^{239+240}Pu$	5.88×10^{-5}	2.04×10^{-4}	4.33×10^{-4}	-6.03×10^{-5}	1.21×10^{-4}	4.44×10^{-4}	6.55×10^{-5}	1.31×10^{-4}	1.77×10^{-4}
			Station A	3rd Quarter		Monthly			
	July			August			September		
^{241}Am	3.29×10^{-4}	4.70×10^{-4}	4.44×10^{-4}	2.21×10^{-4}	6.25×10^{-4}	1.19×10^{-3}	7.22×10^{-4}	6.29×10^{-4}	7.59×10^{-4}
^{238}Pu	0.00×10^{0}	0.00×10^{0}	3.43×10^{-4}	0.00×10^{0}	0.00×10^{0}	2.99×10^{-4}	0.00×10^{0}	0.00×10^{0}	3.10×10^{-4}
$^{239+240}Pu$	0.00×10^{0}	0.00×10^{0}	9.32×10^{-4}	2.21×10^{-4}	3.14×10^{-4}	2.99×10^{-4}	-2.29×10^{-4}	3.26×10^{-4}	1.06×10^{-3}
			Station A	4th Quarter		Monthly			
	October			November			December		
^{241}Am	1.86×10^{-3}	1.41×10^{-3}	1.52×10^{-3}	-2.39×10^{-2}	4.81×10^{-4}	1.29×10^{-3}	2.71×10^{-4}	3.85×10^{-4}	3.67×10^{-4}
^{238}Pu	2.20×10^{-4}	4.40×10^{-4}	8.07×10^{-4}	-2.78×10^{-4}	5.59×10^{-4}	1.49×10^{-3}	1.37×10^{-4}	2.74×10^{-4}	3.69×10^{-4}
$^{239+240}Pu$	1.10×10^{-4}	2.19×10^{-4}	2.97×10^{-4}	0.00×10^{0}	0.00×10^{0}	1.02×10^{-3}	-1.36×10^{-4}	2.73×10^{-4}	1.00×10^{-3}

[a] Total propagated uncertainty.
[b] Minimum detectable concentration.
[c] Station A were composited monthly due to the large number of samples.

In 2001, the weekly gross beta concentrations also varied throughout the year at each station (Figure 4.3). Stations tended to vary together, showing a strong annual pattern.

Concentrations ranged over almost an order of magnitude, from a minimum of $4.71\times10^{-4} \pm 7.88\times10^{-5}$ Bq/m^3 ($1.27\times10^{-2} \pm 2.13\times10^{-3}$ pCi/m^3) to a maximum of $1.70\times10^{-3} \pm 2.04\times10^{-4}$ Bq/m^3 ($4.59\times10^{-2} \pm 5.51\times10^{-3}$ pCi/m^3) (Table 4.2). However, the annual mean concentrations of gross beta activities found at all locations were similar, ranging from $8.37\times10^{-4} \pm 4.17\times10^{-4}$ to $9.28\times10^{-4} \pm 1.86\times10^{-3}$ Bq/m^3 ($2.26\times10^{-2} \pm 1.13\times10^{-2}$ to $2.51\times10^{-2} \pm 5.03\times10^{-2}$ pCi/m^3). There was no significant difference between sampling stations (ANOVA, $p = 0.565$).

Gross alpha and gross beta activity concentrations in 2000 and 2001 were compared using ANOVA to determine whether they had increased since waste began to be received at WIPP (Figure 4.4). There was no significant difference in measured gross alpha ($p = 0.241$) or gross beta ($p = 0.094$) activity concentration between years.

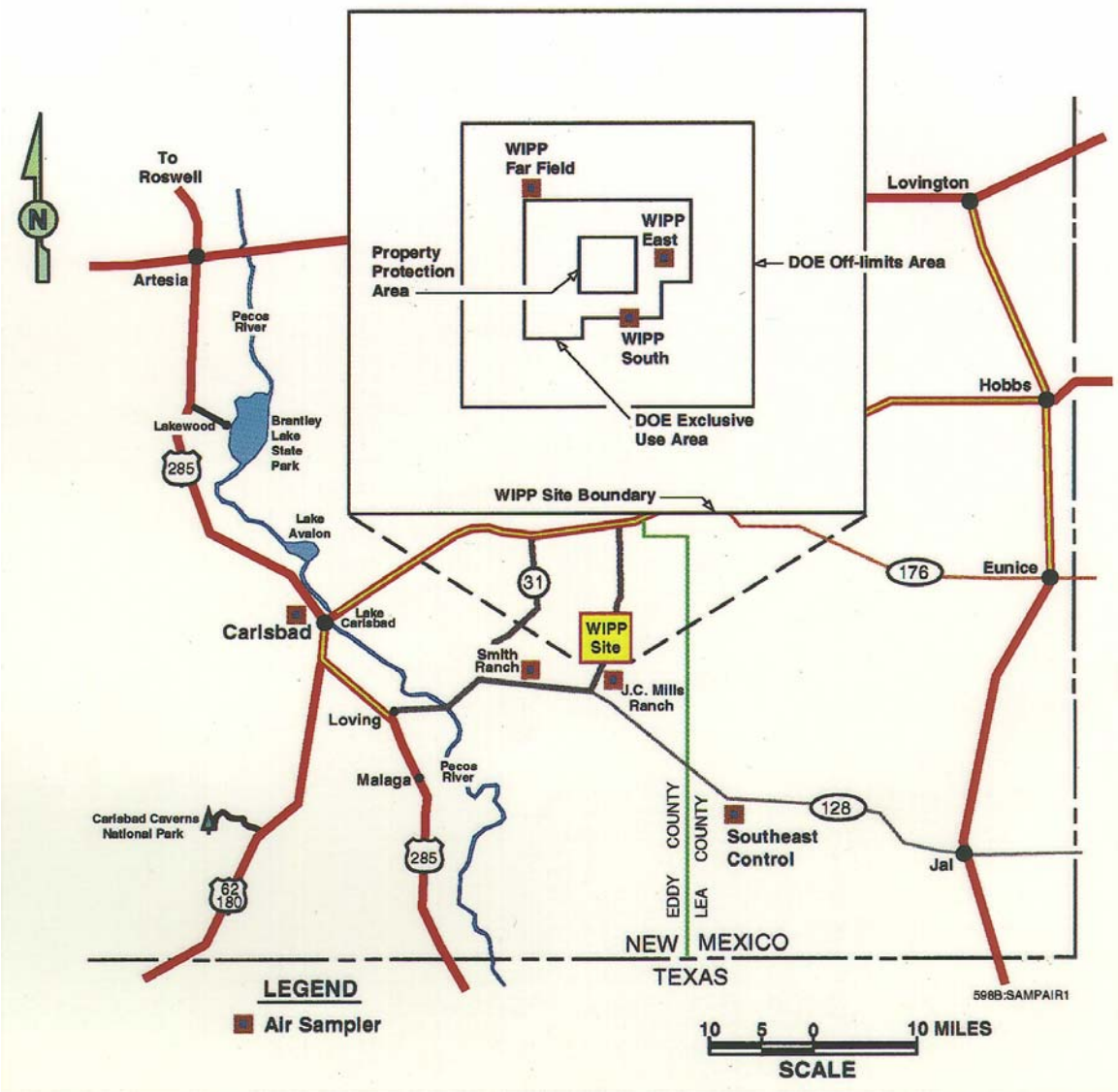


Figure 4.1 - Air Sampling Locations on and Near the WIPP Facility

One duplicate sample was collected every quarter by rotating the portable sampler from one location to another: WEE in the first quarter, WSS in the second quarter, MLR in the third quarter, and SMR in the fourth quarter. The samples were collected by both samplers in identical conditions at all four locations. Duplicate samples were collected and analyzed for the QC of (1) air sampling technique, (2) determination of gross alpha and beta activities, and (3) analysis of the individual radionuclides in airborne particulate. Relative Error Ratios (RER) (see Appendix C) was exceeded once in the weekly gross alpha (RER value 1.03) and were less than one in all of the weekly gross beta measurements. An RER less than one indicates good agreement between duplicates. The duplicate data are provided in Appendix D.

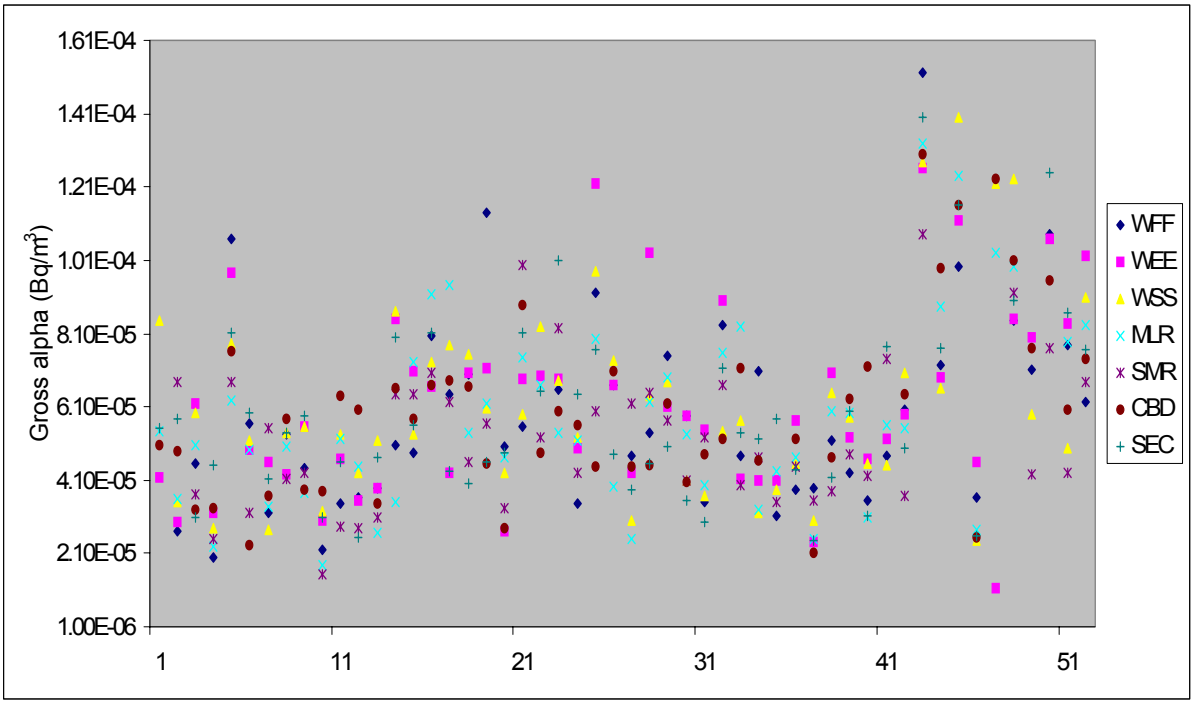


Figure 4.2 - Gross Alpha Activity Concentration Measured in Air Particulates Each Week in 2001. See text for sampling station locations.

Table 4.2 - Annual Mean Gross Alpha and Gross Beta Activity Concentrations (Bq/m^3) Found in Weekly Air Particulate Samples (See Appendix B for sample locations.)

Location	Minimum	2 × TPU[a]	Maximum	2 × TPU	Mean	2 × SD[b]
			Gross Alpha			
CBD	2.11×10^{-5}	1.57×10^{-5}	1.30×10^{-4}	3.87×10^{-5}	5.98×10^{-5}	4.92×10^{-5}
MLR	1.77×10^{-5}	1.45×10^{-5}	1.33×10^{-4}	4.03×10^{-5}	5.83×10^{-5}	5.13×10^{-5}
SEC	2.46×10^{-5}	1.71×10^{-5}	1.40×10^{-4}	4.11×10^{-5}	5.93×10^{-5}	5.07×10^{-5}
SMR	1.52×10^{-5}	1.37×10^{-5}	1.08×10^{-4}	3.68×10^{-5}	5.26×10^{-5}	3.97×10^{-5}
WEE	1.15×10^{-5}	1.72×10^{-5}	1.26×10^{-4}	3.92×10^{-5}	6.16×10^{-5}	5.15×10^{-5}
WFF	1.99×10^{-5}	1.55×10^{-5}	1.52×10^{-4}	4.27×10^{-5}	5.90×10^{-5}	1.18×10^{-4}
WSS	2.47×10^{-5}	1.69×10^{-5}	1.40×10^{-4}	4.08×10^{-5}	6.16×10^{-5}	5.28×10^{-5}
			Gross Beta			
CBD	5.59×10^{-4}	8.38×10^{-5}	1.70×10^{-3}	2.04×10^{-4}	8.83×10^{-4}	4.63×10^{-4}
MLR	5.77×10^{-4}	8.99×10^{-5}	1.56×10^{-3}	1.91×10^{-4}	8.76×10^{-4}	4.33×10^{-4}
SEC	6.13×10^{-4}	9.12×10^{-5}	1.62×10^{-3}	1.93×10^{-4}	9.04×10^{-4}	4.13×10^{-4}
SMR	4.71×10^{-4}	7.88×10^{-5}	1.39×10^{-3}	1.73×10^{-4}	8.37×10^{-4}	4.17×10^{-4}
WEE	5.54×10^{-4}	8.61×10^{-5}	1.64×10^{-3}	1.95×10^{-4}	8.90×10^{-4}	4.58×10^{-4}
WFF	5.87×10^{-4}	8.92×10^{-5}	1.66×10^{-3}	1.98×10^{-4}	9.28×10^{-4}	1.86×10^{-3}
WSS	6.05×10^{-4}	8.86×10^{-5}	1.51×10^{-3}	1.83×10^{-4}	8.67×10^{-4}	4.31×10^{-4}

[a] Total propagated uncertainty
[b] Standard deviation of the mean

4.3 Airborne Particulates

The major pathways for the intake of radioactive materials into the human body are from the inhalation of dust particles and the ingestion of food and drinking water. Plutonium is the major constituent of the TRU wastes to be disposed at the WIPP site. Accordingly, plutonium and other radionuclides of interest were determined in air particulate samples around the WIPP site.

Isotopes of plutonium and americium were analyzed because they are the most significant alpha-emitting radionuclides among the constituents of TRU wastes received at the WIPP site. Uranium isotopes were analyzed because they are prominent alpha-emitting radionuclides in the natural environment.

WIPP analyzed samples for ^{90}Sr, ^{60}Co, and ^{137}Cs in order to demonstrate the ability to quantify these beta and gamma-emitting contaminants should they appear in the TRU waste stream. These radionuclides have been the subject of background studies at WIPP prior to 1999 and continue to be monitored. Potassium-40, a natural gamma-emitting radionuclide which is ubiquitous in the earth's crust, was also monitored because of its possible enhancement in southeastern New Mexico due to potash mining.

Gross alpha and gross beta measurements are used as a screening technique and to identify any seasonal trends. The results are compared to historical values. Any result above the 2 σ warning limit is investigated for sampling error, instrument problems, and any other steps involved in the gross alpha and gross beta analysis. If the above-mentioned were ruled out as a contribution to the high result, a destructive analysis is performed to identify the specific nuclide contributing to the activity.

4.3.1 Sample Preparation

Weekly air particulate samples were collected as described in Section 4.2 and composited for each quarter. The composites were transferred into a Pyrex beaker, spiked with appropriate tracers, and heated in a Muffle furnace at 250°C (482°F) for two hours, followed by two hours at 375°C (707°F) and six hours at 525°C (977°F).

The ash was cooled, transferred quantitatively into a Teflon beaker by rinsing with concentrated nitric acid, and heated with concentrated hydrofluoric acid until completely dissolved. Hydrofluoric acid was removed by evaporating to dryness.

Approximately 25 ml (0.845 oz [ounce]) of concentrated nitric acid and one gram (0.0353 oz) of boric acid were added, heated, and finally evaporated to dryness. The residue was dissolved in 8 M (molar) nitric acid for gamma spectrometry and determinations of ^{90}Sr and alpha-emitting radionuclides.

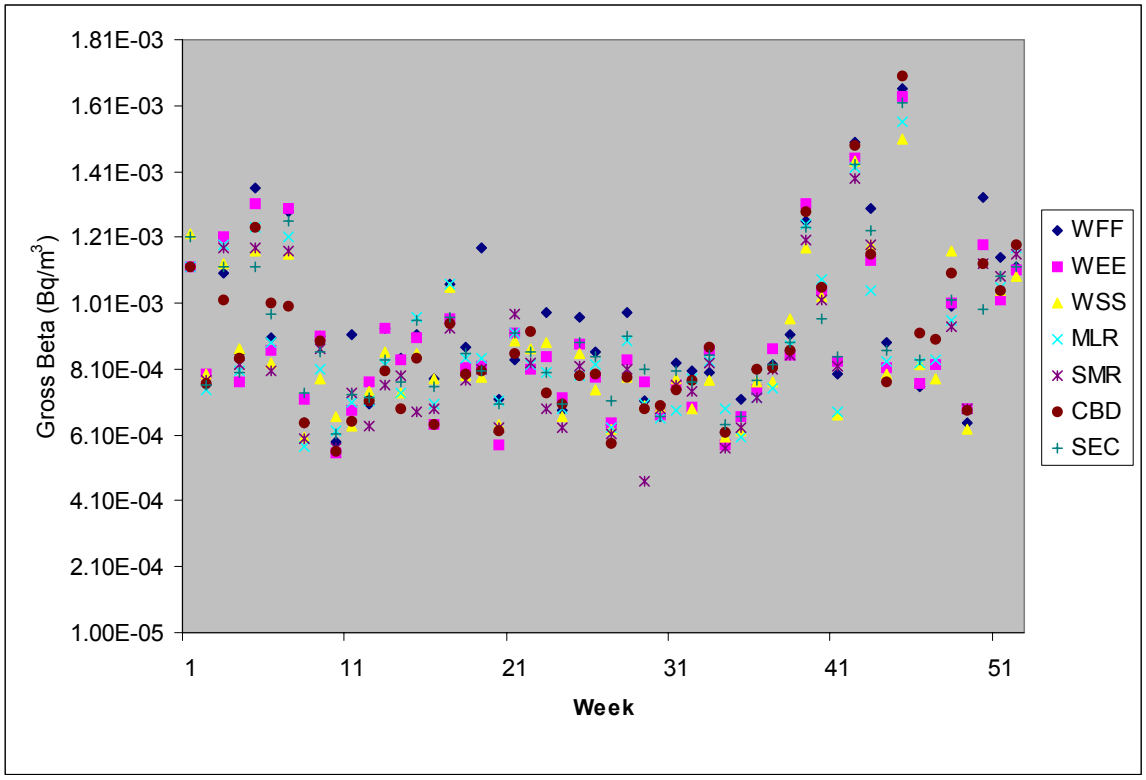


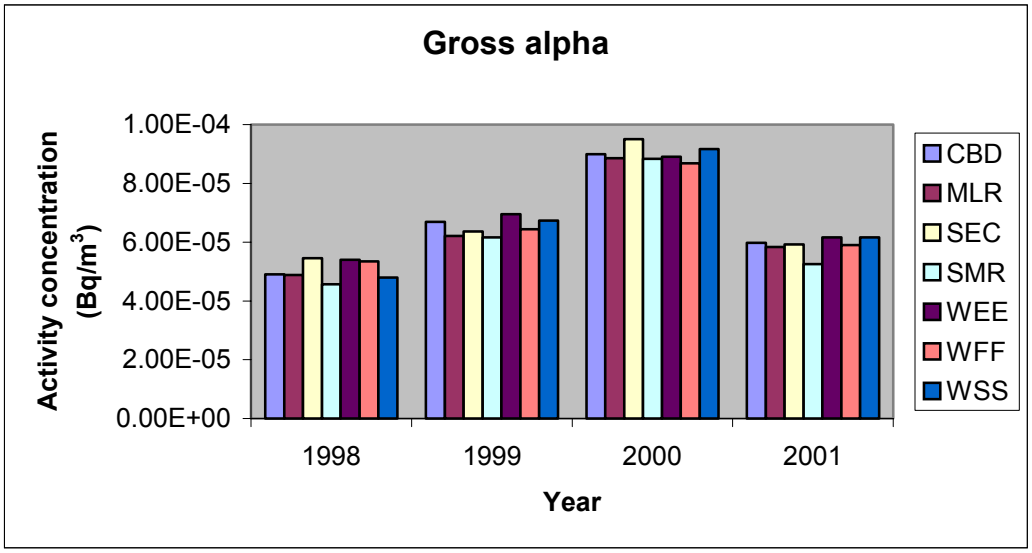
Figure 4.3 - Gross Beta Activity Concentration Measured in Air Particulates Each Week in 2001. See text for sampling station locations.

4.3.2 Determination of Individual Radionuclides

Gamma-emitting radionuclides were measured in the air filters by gamma spectrometry. Strontium-90 and alpha-emitting radionuclides were determined by sequential separation and counting. Determination of actinides involved co-precipitation, ion exchange separation, and alpha spectrometry.

4.3.3 Results and Discussions

The minima, maxima, and means for all stations combined are reported in Table 4.3. Detailed data for each station are reported in Appendix G (Table G.1). Natural uranium isotopes were detected in every composite sample. Concentrations of ^{234}U ranged from $2.01\times10^{-6} \pm 4.48\times10^{-7}$ Bq/m^3 ($5.43\times10^{-5} \pm 1.21\times10^{-5}$ pCi/m^3) at WSS in the first quarter to $4.59\times10^{-6} \pm 8.51\times10^{-7}$ Bq/m^3 ($1.24\times10^{-4} \pm 2.30\times10^{-5}$ pCi/m^3) at WFF in the second quarter (Appendix G, Table G.1). There was no significant difference between concentrations measured in 2000 and 2001 (ANOVA, $p = 0.345$).



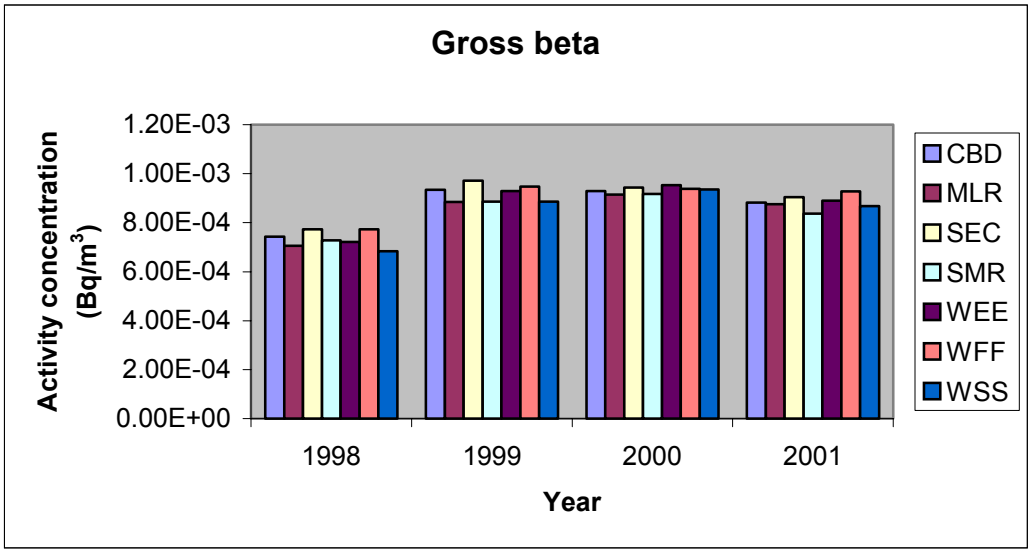


Figure 4.4 - Average Gross Alpha and Beta Activity Concentrations Measured in Air Particulates in Four Consecutive Years. The year 1999 was the first year in which radioactivity was stored in WIPP. See text for sampling station locations.

Table 4.3 - Minimum, Maximum and Average Radionuclide Concentrations (Bq/m^3) in Air Filter Composites from Stations Surrounding the WIPP Site. See Appendix B for locations. See Appendix G for supporting data.

Radionuclide		[RN][a]	2×TPU[b]	MDC[c]
^{241}Am	Minimum	-4.26×10^{-8}	6.40×10^{-8}	3.81×10^{-8}
	Maximum	6.03×10^{-8}	6.11×10^{-8}	2.17×10^{-7}
	Average	1.87×10^{-8}	4.88×10^{-8}	8.58×10^{-8}
^{238}Pu	Minimum	-3.36×10^{-8}	6.73×10^{-8}	3.92×10^{-8}
	Maximum	2.07×10^{-7}	2.23×10^{-7}	3.05×10^{-7}
	Average	2.23×10^{-8}	9.37×10^{-8}	1.43×10^{-7}
$^{239+240}$Pu	Minimum	-2.96×10^{-8}	5.96×10^{-8}	3.52×10^{-8}
	Maximum	1.08×10^{-7}	1.34×10^{-7}	2.18×10^{-7}
	Average	1.62×10^{-8}	5.36×10^{-8}	7.84×10^{-8}
^{234}U	Minimum	2.01×10^{-6}	4.48×10^{-7}	3.52×10^{-8}
	Maximum	4.59×10^{-6}	8.51×10^{-7}	1.29×10^{-7}
	Average	2.96×10^{-6}	1.66×10^{-6}	5.80×10^{-8}
^{235}U	Minimum	0.00×10^{0}	0.00×10^{0}	4.44×10^{-8}
	Maximum	8.18×10^{-7}	9.29×10^{-8}	2.10×10^{-7}
	Average	1.69×10^{-7}	2.82×10^{-7}	7.74×10^{-8}
^{238}U	Minimum	1.75×10^{-6}	4.18×10^{-7}	3.51×10^{-8}
	Maximum	4.81×10^{-6}	9.55×10^{-7}	1.82×10^{-7}
	Average	2.90×10^{-6}	1.63×10^{-6}	6.42×10^{-8}
^{40}K	Minimum	-5.29×10^{-5}	2.37×10^{-4}	1.27×10^{-4}
	Maximum	6.44×10^{-3}	2.46×10^{-4}	8.84×10^{-4}
	Average	6.90×10^{-4}	3.11×10^{-3}	3.31×10^{-4}
^{60}Co	Minimum	-1.32×10^{-5}	2.94×10^{-5}	1.98×10^{-5}
	Maximum	3.96×10^{-5}	4.00×10^{-5}	5.07×10^{-5}
	Average	6.32×10^{-6}	2.72×10^{-5}	2.89×10^{-5}
^{90}Sr	Minimum	-7.47×10^{-6}	5.66×10^{-6}	6.99×10^{-6}
	Maximum	6.33×10^{-6}	4.40×10^{-6}	1.44×10^{-5}
	Average	2.01×10^{-7}	7.08×10^{-6}	8.77×10^{-6}
^{137}Cs	Minimum	-3.81×10^{-5}	3.28×10^{-5}	1.69×10^{-5}
	Maximum	3.70×10^{-5}	3.70×10^{-5}	4.88×10^{-5}
	Average	-7.71×10^{-7}	3.35×10^{-5}	2.62×10^{-5}

[a] [RN] = Radionuclide concentration
[b] Total Propagated Uncertainty (Standard Deviation, in the case of the mean)
[c] Minimum Detectable Concentration

The activity concentration of ^{235}U in the natural environment is very low compared to the concentrations of ^{234}U and ^{238}U (1 µg of natural uranium contains 12.2 mBq [millibecquerel] [0.33 pCi] of ^{238}U, 0.56 mBq [0.01 pCi] of ^{235}U, and 12.8 mBq [0.35 pCi] of ^{234}U); therefore, the amount of ^{235}U in air particulate samples is expected to be lower. Uranium-235 was detected in approximately 75 percent of the quarterly composite samples. The lowest concentration ($0.00\times10^{0} \pm 0.00\times10^{0}$ Bq/m^3 [$0.00\times10^{0} \pm 0.00\times10^{0}$ pCi/m^3]) was measured at WFF in the fourth quarter and the highest concentration ($8.18\times10^{-7} \pm 9.29\times10^{-8}$ Bq/m^3 [$2.21\times10^{-5} \pm 2.51\times10^{-6}$ pCi/m^3]) was found at MLR in the first quarter (Table G.1).

Uranium-238 was also, as expected, detected in 100 percent of the composite air filters. Concentrations ranged from $1.75\times10^{-6} \pm 4.18\times10^{-7}$ Bq/m^3 ($4.73\times10^{-5} \pm 1.13\times10^{-5}$ pCi/m^3) at WFF in the first quarter to $4.81\times10^{-6} \pm 9.55\times10^{-7}$ Bq/m^3 ($1.30\times10^{-4} \pm 2.58\times10^{-5}$ pCi/m^3) at CBD in the second quarter (Table G.1).

Neither ^{238}Pu nor $^{239+240}$Pu were detected in any sample in 2001. Americium-241 was also not detected in any of the quarterly composites.

Concentrations of ^{40}K (Table G.1) were detected in approximately 50 percent of the samples. The minimum ($-5.29\times10^{-5} \pm 2.37\times10^{-4}$ Bq/m^3 [$1.43\times10^{-3} \pm 6.41\times10^{-3}$ pCi/m^3]) was found at WFF in the second quarter, while the maximum ($6.44\times10^{-3} \pm 2.46\times10^{-4}$ Bq/m^3 [$1.74\times10^{-1} \pm 6.65\times10^{-3}$ pCi/m^3]) was found at WEE in the second quarter.

Cesium-137 was not detected in any of the quarterly composite samples. Cobalt-60 was detected in one sample. Strontium-90 was never detected in a quarterly composite air filter in 2001.

Duplicate air particulate samples were collected by rotating the portable sampler from one location to another every quarter: WEE in the first quarter, WSS in the second quarter, MLR in the third quarter, and SMR in the fourth quarter. The samples were collected by both samplers in identical conditions at all four locations. The duplicate samples were analyzed to check the reproducibility of the data. The results are given in Table 4.4. The original and duplicate results for ^{234}U, ^{238}U, and ^{40}K were compared using the RER. The results for all other radionuclides were excluded because of insufficient detections for a meaningful test. Relative Error Ratios were less than one for all results except ^{234}U and ^{238}U at SMR fourth quarter due to the non-homogenous deposit of airborne particulates on the filter. Sample WSS in the second quarter failed to meet RER criteria for ^{40}K because the gamma software had a problem calculating the activity. The problem was isolated to this incidence. The sample could not be reanalyzed since the aliquot was used for actinide analysis.

The results obtained for the concentrations of ^{238}Pu, $^{239+240}$Pu, and ^{241}Am in air particulates compared favorably with those measured by the EEG (Table 4.5). The annual mean concentrations of these radionuclides were very low, and most samples collected by either WIPP or EEG did not contain detectable concentrations.

Table 4.4 - Results of Duplicate Composite Air Filter Sampling. Units are Bq/m^3. See Appendix B for sampling stations.

Location	Quarter	[RN][a]	2×TPU[b]	MDC[c]	RER[d]
			^{40}K		
WEE	1	2.46×10^{-4}	2.43×10^{-4}	3.06×10^{-4}	0.155
WEE Dup.	1	2.93×10^{-4}	1.85×10^{-4}	2.40×10^{-4}	
WSS	2	2.93×10^{-4}	1.84×10^{-4}	2.41×10^{-4}	64.70
WSS Dup.	2	7.47×10^{-2}	1.14×10^{-3}	7.96×10^{-4}	
MLR	3	2.26×10^{-4}	1.04×10^{-4}	1.36×10^{-4}	0.035
MLR Dup.	3	2.21×10^{-4}	9.55×10^{-5}	1.22×10^{-4}	
SMR	4	4.29×10^{-4}	3.64×10^{-4}	5.74×10^{-4}	0.607
SMR Dup.	4	1.56×10^{-4}	2.64×10^{-4}	3.23×10^{-4}	
			^{234}U		
WEE	1	2.34×10^{-6}	5.40×10^{-7}	1.29×10^{-7}	0.172
WEE Dup.	1	2.47×10^{-6}	5.39×10^{-7}	4.01×10^{-8}	
WSS	2	4.29×10^{-6}	8.62×10^{-7}	4.18×10^{-8}	0.025
WSS Dup.	2	4.26×10^{-6}	8.29×10^{-7}	3.99×10^{-8}	
MLR	3	2.91×10^{-6}	6.33×10^{-7}	4.26×10^{-8}	0.369
MLR Dup.	3	2.60×10^{-6}	5.51×10^{-7}	3.81×10^{-8}	
SMR	4	2.58×10^{-6}	5.99×10^{-7}	5.33×10^{-8}	2.760
SMR Dup.	4	3.33×10^{-7}	5.51×10^{-7}	1.09×10^{-7}	
			^{238}U		
WEE	1	2.35×10^{-6}	5.40×10^{-7}	4.29×10^{-8}	0.288
WEE Dup.	1	2.14×10^{-6}	4.85×10^{-7}	9.59×10^{-7}	
WSS	2	4.37×10^{-6}	8.73×10^{-7}	4.14×10^{-8}	0.113
WSS Dup.	2	4.51×10^{-6}	8.73×10^{-7}	3.96×10^{-8}	
MLR	3	2.53×10^{-6}	5.70×10^{-7}	1.15×10^{-7}	0.000
MLR Dup.	3	2.53×10^{-6}	5.40×10^{-7}	1.03×10^{-8}	
SMR	4	2.56×10^{-6}	6.03×10^{-7}	1.82×10^{-7}	2.797
SMR Dup.	4	2.60×10^{-7}	5.59×10^{-7}	1.08×10^{-7}	

[a] [RN] = Radionuclide concentration
[b] Total propagated uncertainty
[c] Minimum detectable concentration
[d] Relative Error Ratio

Table 4.5 - Preliminary Quarterly Average Radionuclide Concentrations (Bq/m^3) Measured in Air Particulate Samples by the Environmental Evaluation Group in 2001

	Quarter			
	1	2	3	4
		^{241}Am		
Concentration	2.99×10^{-8}	2.52×10^{-8}	9.59×10^{-9}	NR[b]
2×SD[a]	3.53×10^{-8}	3.49×10^{-8}	3.50×10^{-8}	NR
		^{238}Pu		
Concentration	-1.51×10^{-9}	1.28×10^{-8}	-8.32×10^{-9}	NR
2×SD	4.20×10^{-8}	4.46×10^{-8}	-4.29×10^{-8}	NR
		$^{239+240}$Pu		
Concentration	6.21×10^{-9}	2.46×10^{-8}	8.42×10^{-9}	NR
2×SD	2.05×10^{-8}	2.29×10^{-8}	1.97×10^{-8}	NR

[a] Standard Deviation.
[b] Not reported

4.4 Groundwater

4.4.1 Sample Collection

Groundwater samples were collected from seven different wells around the WIPP site as shown in Figure 6.1. Approximately three bore volumes (approximately 3,800 l [1,000 gal]) of water were pumped out of these wells before collecting approximately 38 l (10 gal) of water samples. The water samples were collected from depths ranging from 180-270 m (600-900 ft) from six wells (WQSP-1 to WQSP-6), and from a depth of 69 m (225 ft) from WQSP-6A. Samples were collected twice in 2001. Approximately 8 l (2 gal) of water were sent to the laboratory for the determination of radionuclides of interest. The rest of the samples were used to analyze for nonradiological parameters or were put into storage. The samples were acidified to pH $\leq$ 2 by adding concentrated nitric acid drop by drop.

4.4.2 Determination of Individual Radionuclides

The acidified water samples were used for the determination of gamma-emitting radionuclides, such as ^{40}K, ^{60}Co, and ^{137}Cs, by gamma-spectrometry. An aliquot of approximately 0.5 l (16.9 oz) was used for the determination of ^{90}Sr. Another aliquot was used for the sequential determinations of the uranium isotopes, the plutonium isotopes, and ^{241}Am by alpha spectrometry, which involved the co-precipitation of actinides with iron carrier, ion exchange chromatographic separation of individual radionuclides, source preparation by micro-precipitating, and alpha spectrometry.

4.4.3 Results and Discussions

Isotopes of naturally-occurring uranium were detected in every well in 2001 (Table 4.6). The mean concentrations of ^{234}U ranged from $2.53\times10^{-1} \pm 7.69\times10^{-3}$ Bq/l (becquerels per liter) ($6.84\times10^{0} \pm 2.08\times10^{-1}$ pCi/l) (picoCuries per liter) in WQSP-6A to $1.29\times10^{0} \pm 1.90\times10^{-1}$ Bq/l ($3.49\times10^{1} \pm 5.14\times10^{0}$ pCi/l) in WQSP-1. Uranium-235 ranged from

$5.88\times10^{-3} \pm 1.13\times10^{-3}$ Bq/l ($1.59\times10^{-1} \pm 3.05\times10^{-2}$ pCi/l) in WQSP-3 to $3.34\times10^{-2} \pm 2.95\times10^{-2}$ Bq/l ($9.02\times10^{-1} \pm 7.97\times10^{-1}$ pCi/l) in WQSP-1. The mean concentration of ^{238}U ranged from $4.14\times10^{-2} \pm 1.13\times10^{-3}$ Bq/l ($1.12\times10^{0} \pm 3.05\times10^{-1}$ pCi/l) in WQSP-3 to $2.11\times10^{-1} \pm 2.15\times10^{-2}$ Bq/l ($5.70\times10^{0} \pm 5.81\times10^{-1}$ pCi/l) in WQSP-1.

Table 4.6 - Average Annual Radionuclide Concentrations (Bq/l) in Groundwater from Wells at the WIPP Site. See Chapter 6 for the sampling locations.

	Mean	2 × SD[a]	MDC[b]	Mean	2 × SD	MDC	Mean	2 × SD	MDC
Location	^{241}Am			^{238}Pu			$^{239+240}Pu$		
WQSP-1	3.99×10^{-4}	7.00×10^{-4}	7.59×10^{-4}	2.93×10^{-4}	1.53×10^{-4}	9.45×10^{-4}	5.79×10^{-5}	1.61×10^{-4}	4.79×10^{-4}
WQSP-2	0.00×10^{0}	0.00×10^{0}	1.41×10^{-3}	2.19×10^{-4}	1.36×10^{-4}	8.82×10^{-4}	-2.19×10^{-4}	1.35×10^{-4}	1.44×10^{-3}
WQSP-3	5.20×10^{-4}	5.39×10^{-4}	1.91×10^{-3}	-9.56×10^{-5}	2.65×10^{-4}	2.28×10^{-3}	0.00×10^{0}	0.00×10^{0}	6.64×10^{-4}
WQSP-4	3.00×10^{-4}	3.29×10^{-4}	8.55×10^{-4}	2.15×10^{-4}	2.52×10^{-4}	3.75×10^{-4}	1.44×10^{-5}	3.84×10^{-4}	6.64×10^{-4}
WQSP-5	-9.62×10^{-5}	2.67×10^{-4}	1.39×10^{-3}	1.08×10^{-4}	2.99×10^{-4}	7.01×10^{-4}	5.40×10^{-5}	1.50×10^{-4}	6.01×10^{-4}
WQSP-6	-1.46×10^{-4}	8.56×10^{-5}	1.07×10^{-3}	5.22×10^{-4}	2.39×10^{-3}	1.82×10^{-3}	-9.29×10^{-5}	6.83×10^{-4}	1.46×10^{-3}
WQSP-6A	2.11×10^{-4}	7.08×10^{-5}	1.12×10^{-3}	3.40×10^{-4}	5.33×10^{-5}	1.03×10^{-3}	-5.98×10^{-5}	1.66×10^{-4}	6.57×10^{-4}
	^{234}U			^{235}U			^{238}U		
WQSP-1	1.29×10^{-1}	1.90×10^{-1}	6.44×10^{-4}	3.34×10^{-2}	2.95×10^{-2}	1.32×10^{-3}	2.11×10^{-1}	2.15×10^{-2}	6.40×10^{-4}
WQSP-2	1.15×10^{0}	1.54×10^{-1}	3.86×10^{-4}	1.76×10^{-2}	1.26×10^{-2}	4.75×10^{-4}	1.88×10^{-1}	1.79×10^{-2}	6.62×10^{-4}
WQSP-3	2.71×10^{-1}	4.05×10^{-2}	9.18×10^{-4}	5.88×10^{-3}	1.13×10^{-3}	6.42×10^{-4}	4.14×10^{-2}	1.13×10^{-2}	5.18×10^{-4}
WQSP-4	5.31×10^{-1}	1.54×10^{-2}	2.26×10^{-3}	8.20×10^{-3}	5.13×10^{-5}	6.48×10^{-4}	8.90×10^{-2}	1.18×10^{-2}	5.22×10^{-4}
WQSP-5	5.75×10^{-1}	1.28×10^{-1}	1.17×10^{-3}	8.10×10^{-3}	1.33×10^{-3}	1.55×10^{-3}	8.33×10^{-2}	1.33×10^{-2}	5.28×10^{-4}
WQSP-6	5.48×10^{-1}	7.18×10^{-3}	1.44×10^{-3}	1.22×10^{-2}	1.44×10^{-2}	9.03×10^{-4}	7.47×10^{-2}	1.64×10^{-2}	7.29×10^{-3}
WQSP-6A	2.53×10^{-1}	7.69×10^{-3}	3.71×10^{-4}	9.10×10^{-3}	2.05×10^{-3}	8.81×10^{-4}	1.33×10^{-1}	3.59×10^{-3}	3.69×10^{-4}
	^{137}Cs			^{60}Co			^{40}K		
WQSP-1	-1.13×10^{-2}	9.29×10^{-2}	4.40×10^{-1}	7.57×10^{-2}	7.68×10^{-1}	4.62×10^{-1}	2.15×10^{1}	2.97×10^{0}	5.55×10^{0}
WQSP-2	-2.52×10^{-1}	5.03×10^{-1}	5.68×10^{-1}	5.22×10^{-1}	2.56×10^{-1}	5.81×10^{-1}	1.57×10^{1}	5.64×10^{1}	8.97×10^{0}
WQSP-3	-4.81×10^{-3}	4.89×10^{-1}	4.55×10^{-1}	1.09×10^{-1}	2.72×10^{-2}	4.96×10^{-1}	5.20×10^{1}	1.59×10^{1}	6.08×10^{0}
WQSP-4	-1.27×10^{-1}	4.56×10^{-1}	3.62×10^{-1}	6.44×10^{-2}	3.59×10^{-1}	4.16×10^{-1}	2.57×10^{1}	8.20×10^{1}	3.52×10^{0}
WQSP-5	-8.57×10^{-2}	7.14×10^{-1}	4.09×10^{-1}	3.68×10^{-2}	4.32×10^{-1}	4.44×10^{-1}	1.02×10^{1}	4.00×10^{0}	4.31×10^{0}
WQSP-6	-3.86×10^{-1}	4.78×10^{-1}	3.82×10^{-1}	1.73×10^{-1}	4.91×10^{-1}	4.28×10^{-1}	6.14×10^{0}	5.13×10^{1}	4.01×10^{0}
WQSP-6A	8.29×10^{-2}	5.23×10^{-2}	3.90×10^{-1}	1.44×10^{-1}	7.28×10^{-2}	4.18×10^{-1}	6.08×10^{0}	7.34×10^{0}	4.52×10^{0}
	^{90}Sr			^{226}Ra			^{228}Ra		
WQSP-1	-1.13×10^{-2}	2.93×10^{-2}	4.37×10^{-2}	5.52×10^{0}	5.49×10^{-1}	3.59×10^{-2}	1.04×10^{0}	1.36×10^{-1}	1.38×10^{-1}
WQSP-2	-5.16×10^{-3}	1.45×10^{-2}	2.93×10^{-2}	3.88×10^{0}	8.61×10^{-2}	2.57×10^{-2}	5.14×10^{-1}	1.26×10^{-1}	1.25×10^{-1}
WQSP-3	-9.23×10^{-3}	6.28×10^{-2}	4.43×10^{-2}	6.75×10^{0}	6.54×10^{-1}	3.16×10^{-2}	1.10×10^{0}	1.84×10^{-1}	1.25×10^{-1}
WQSP-4	1.60×10^{-2}	1.16×10^{-1}	3.25×10^{-2}	8.86×10^{0}	1.04×10^{0}	3.53×10^{-2}	1.36×10^{0}	2.60×10^{-1}	1.49×10^{-1}
WQSP-5	9.84×10^{-3}	8.14×10^{-2}	6.11×10^{-2}	2.71×10^{0}	1.22×10^{-1}	2.35×10^{-2}	3.83×10^{-1}	3.08×10^{-3}	1.18×10^{-1}
WQSP-6	1.65×10^{-3}	8.10×10^{-2}	5.57×10^{-2}	1.26×10^{0}	7.69×10^{2}	1.81×10^{2}	1.70×10^{-1}	1.27×10^{-1}	1.11×10^{-1}
WQSP-6A	1.21×10^{-2}	6.72×10^{-2}	5.70×10^{-2}	4.07×10^{3}	3.08×10^{3}	1.37×10^{2}	-6.48×10^{-3}	9.38×10^{-2}	1.06×10^{-1}

[a] Standard deviation of the mean
[b] Minimum detectable concentration

The concentrations of uranium isotopes in water samples collected from these wells were compared between the years 2000 and 2001. There was a significant difference in the concentration of uranium isotopes (ANOVA, ^{234}U $p = 0.008$, ^{238}U $p=0.009$). The average concentration for both nuclides was approximately two times higher in 2001. Two different laboratories performed the analysis in years 2000 and 2001, and

employed two different methods. The groundwater had a high content of total dissolved solids, which caused the average chemical recovery of the samples to be less in 2001. The lower chemical recovery causes the activity to be higher. The 2001 values are within the 2 σ limit.

Plutonium-238, $^{239+240}$Pu, and ^{241}Am were also analyzed in these groundwater samples (Table 4.6). Neither $^{239+240}$Pu nor ^{241}Am were detected in any sample. The concentration of ^{238}Pu was greater than the MDC in one sample from well WQSP-6 during the spring sampling ($1.38\times10^{-3} \pm 1.05\times10^{-3}$ Bq/l; MDC = 1.13×10^{-3} Bq/l [$3.73\times10^{-2} \pm 2.84\times10^{-2}$ pCi/l; MDC = 3.05×10^{-2} pCi/l]). However, this result was very close to the MDC. All wells' sample results and means were below the detection limit for $^{239+240}$Pu. Analysis of variance did not show differences in ^{238}Pu, $^{239+240}$Pu, or ^{241}Am (ANOVA ^{238}Pu $p = 0.619$, $^{239+240}$Pu $p = 0.520$, ^{241}Am $p = 0.423$) between years 2000 and 2001.

As discussed in last year's annual Site Environmental Report (DOE/WIPP 01-2225), groundwater results from wells WQSP-1, WQSP-3, and WQSP-4 have exhibited a pattern of activity above the MDC for ^{238}Pu and ^{241}Am. In order to help explain these apparently above background concentrations, WIPP began analyzing groundwater for ^{226}Ra and ^{228}Ra during the fall sampling of 2000. Radium-226 and ^{228}Ra were detected in 100 percent of the samples. The mean concentrations were all above the mean detection limits (Table 4.6). However, the concentrations of ^{226}Ra in water from wells WQSP-1, WQSP-3, and WQSP-4 were all lower than those reported in the 1995 Annual Site Environmental Report (6.0 ± 0.06 Bq/l, 7.8 ± 0.06 Bq/l, and 9.1 ± 0.07 Bq/l, respectively).

These results are important because one decay product of ^{226}Ra, ^{222}Rn, emits alpha particles with an energy of 5.489 MeV, very close to the most abundant alpha energy of ^{241}Am (5.486 MeV) and ^{238}Pu (5.499 MeV). Because these energies are close, the region of interest in the alpha spectrum from the groundwater samples likely contained counts originating from ^{222}Rn that were identified as ^{238}Pu or ^{241}Am. Additional ^{226}Ra progeny were also likely present. The solubility of the components can vary causing the ^{222}Rn activity and associated ^{226}Ra progeny to appear in some analyses, but not all. This phenomenon may explain the trend of seemingly high concentrations of ^{238}Pu and ^{241}Am observed in some groundwater samples over time. These patterns will become more apparent as more samples are analyzed for ^{226}Ra.

Cesium-137 and ^{60}Co were not detected in any of the samples. Potassium-40 was detected in all the wells except for the spring sampling round WQSP-6A. Strontium-90 was not detectable in any of the wells.

4.5 Surface Water

4.5.1 Sample Collection

Fourteen different locations around the WIPP site, as shown in Figure 4.5, were identified for collecting the surface water samples (see Appendix B for location codes). Samples were collected once in 2001 from ten sampling locations. If the surface water

collection location was dry, sediment was collected. Sediment results are described in Section 4.7.

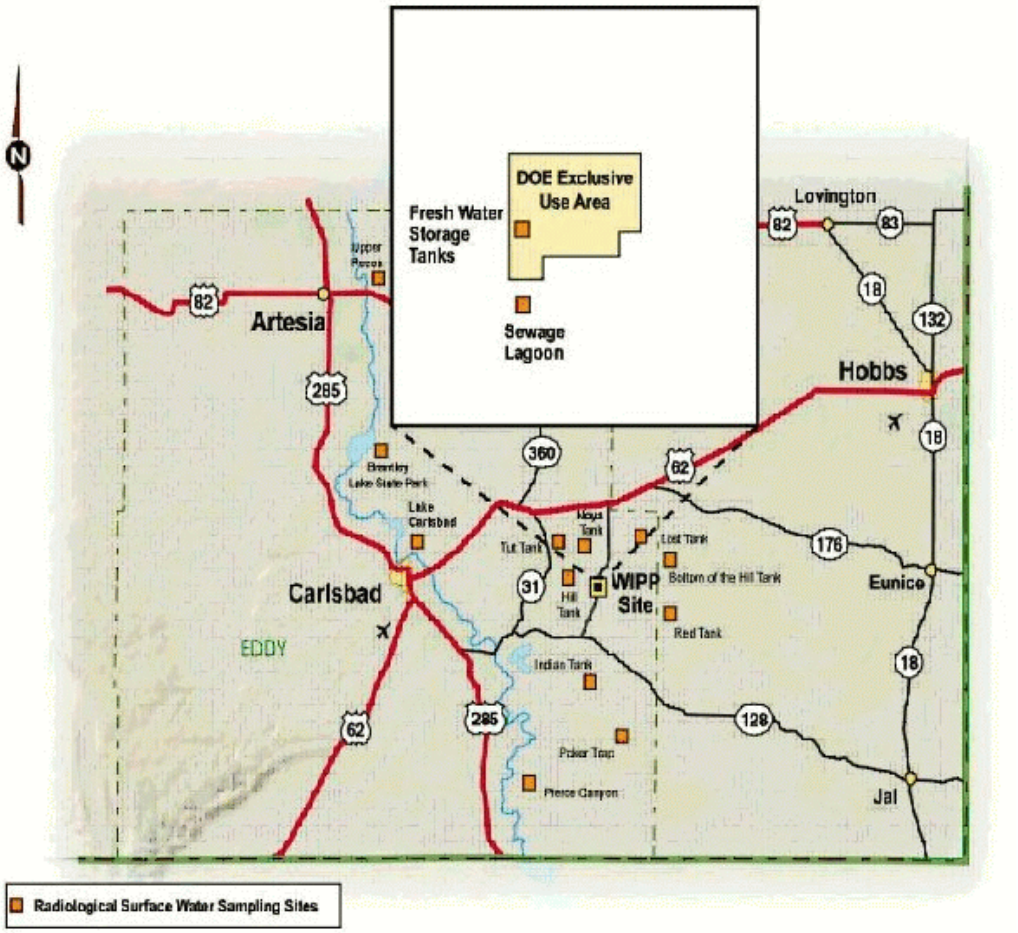


Figure 4.5 - Surface Water Sampling Locations in 2001

Water from the sampling location was used to rinse 3.78-l (1-gal) polyethylene containers several times. Approximately 3.78 l (1 gal) of water was collected from each location. The samples were acidified immediately after collection with concentrated nitric acid to pH $\leq$ 2. Later, the samples were shipped to the laboratory for analysis. Chain of custody was maintained throughout the process.

4.5.2 Determination of Individual Radionuclides

Gamma-spectrometry was used for the determination of ^{40}K, ^{60}Co, and ^{137}Cs. Strontium-90, a beta-emitting radionuclide, was determined by chemical separation and counting it on the gas proportional counter. Uranium, plutonium, and americium were determined by alpha spectrometry. These alpha-emitting radionuclides were separated from the bulk of water samples by co-precipitation with an iron carrier. Ion-exchange

chromatography was used for the separation of individual radionuclides. Finally, the samples were counted by alpha spectrometry.

4.5.3 Results and Discussions

Isotopes of natural uranium were detected in surface water at every sampling location (Table 4.7). Uranium-234 was lowest at Coyote Well (COW) ($4.14\times10^{-4} \pm 5.11\times10^{-4}$ Bq/l [$1.12\times10^{-2} \pm 1.38\times10^{-2}$ pCi/l]) and highest at Pierce Canyon (PCN) ($2.18\times10^{-1} \pm 3.42\times10^{-2}$ Bq/l [$5.89\times10^{0} \pm 9.24\times10^{-1}$ pCi/l]). Uranium-235 was detected in 54 percent of the samples. Concentrations ranged from $1.28\times10^{-4} \pm 2.56\times10^{-4}$ Bq/l ($3.46\times10^{-3} \pm 6.92\times10^{-2}$ pCi/l) at COW to $6.51\times10^{-3} \pm 2.06\times10^{-3}$ Bq/l ($1.76\times10^{-1} \pm 5.57\times10^{-2}$ pCi/l) at PCN. Concentrations of ^{238}U, detected in all samples, ranged from $0.00\times10^{0} \pm 0.00\times10^{0}$ Bq/l ($0.00\times10^{0} \pm 0.00\times10^{0}$ pCi/l) at PCN to $1.08\times10^{-1} \pm 1.75\times10^{-2}$ Bq/l ($2.92\times10^{0} \pm 4.73\times10^{-1}$ pCi/l) at PCN.

Results for uranium concentrations in 2001 samples were compared with the uranium concentrations in 2000 samples. There was no significant difference in the concentration of any uranium isotope between years (ANOVA, ^{234}U $p = 0.227$, ^{235}U $p = 0.869$, ^{238}U $p = 0.817$).

Table 4.7 - Uranium Concentrations (Bq/l) in Surface Water Near the WIPP Site. See Appendix B for the sampling locations.

	[RN][a]	2 × TPU[b]	MDC[c]	[RN]	2 × TPU	MDC	[RN]	2 × TPU	MDC
Location	^{234}U			^{235}U			^{238}U		
BRA	1.07×10^{-1}	1.79×10^{-2}	2.92×10^{-4}	3.19×10^{-3}	1.44×10^{-3}	9.81×10^{-4}	5.44×10^{-2}	9.69×10^{-3}	7.92×10^{-4}
CBD	1.32×10^{-1}	2.25×10^{-2}	2.96×10^{-4}	3.64×10^{-3}	1.52×10^{-3}	3.66×10^{-4}	6.14×10^{-2}	1.11×10^{-2}	2.95×10^{-4}
FWT	5.29×10^{-2}	9.36×10^{-3}	2.77×10^{-4}	1.39×10^{-3}	9.36×10^{-4}	9.29×10^{-4}	2.28×10^{-2}	4.66×10^{-3}	2.76×10^{-4}
HIL	2.19×10^{-2}	4.96×10^{-3}	3.59×10^{-4}	9.81×10^{-4}	8.18×10^{-4}	4.44×10^{-4}	1.85×10^{-2}	4.37×10^{-3}	3.58×10^{-4}
IDN	1.21×10^{-2}	3.00×10^{-3}	7.99×10^{-4}	9.36×10^{-4}	8.14×10^{-4}	9.84×10^{-4}	1.22×10^{-2}	3.00×10^{-3}	2.92×10^{-4}
NOY	1.10×10^{-2}	3.22×10^{-3}	4.14×10^{-4}	5.66×10^{-4}	6.59×10^{-4}	5.11×10^{-4}	8.21×10^{-3}	2.65×10^{-3}	4.11×10^{-4}
PCN	2.18×10^{-1}	3.42×10^{-2}	7.62×10^{-4}	6.51×10^{-3}	2.06×10^{-3}	3.45×10^{-4}	1.08×10^{-1}	1.75×10^{-2}	2.79×10^{-4}
SWL	4.48×10^{-2}	9.51×10^{-3}	4.22×10^{-4}	1.92×10^{-4}	6.66×10^{-4}	1.42×10^{-3}	1.63×10^{-2}	4.29×10^{-3}	4.22×10^{-4}
TUT	9.66×10^{-3}	2.49×10^{-3}	2.76×10^{-4}	5.03×10^{-4}	5.07×10^{-4}	3.40×10^{-4}	7.81×10^{-3}	2.15×10^{-3}	2.75×10^{-4}
UPR	8.14×10^{-2}	1.42×10^{-2}	3.03×10^{-4}	3.59×10^{-3}	1.52×10^{-3}	3.74×10^{-4}	4.51×10^{-2}	8.36×10^{-3}	3.02×10^{-4}

[a] [RN] = Radionuclide concentration
[b] Total propagated uncertainty
[c] Minimum detectable concentration

Analysis of variance was also used to test for differences in uranium concentration between sampling locations. Differences were detected for each uranium isotope ($p < 0.001$). Pierce Canyon had the highest concentrations, with other locations along the Pecos River (Brantley Lake [BRA], Carlsbad [CBD], and Upper Pecos River [UPR]) in another homogeneous subset of the data. All of the surface tanks were in another homogeneous subset having the lowest concentrations. Large spatial variations in uranium concentration in surface water are expected because of the different characteristics of the water bodies and the underlying sediments. For example, the PCN site drains a large surface area and leaches uranium from the sediments. The Tut Tank (TUT) is mostly rainwater and has relatively little contact with sediments.

These water samples were also analyzed for ^{238}Pu, $^{239+240}Pu$, and ^{241}Am (Table 4.8). Concentrations of ^{241}Am, ^{238}Pu and $^{239+240}Pu$ were below the MDC in every sample.

Potassium-40, ^{60}Co, ^{90}Sr, and ^{137}Cs are ubiquitous in soils and might reasonably be expected in surface water samples due to leaching from sediments. As expected, ^{40}K was detected in 70 percent of the surface water samples (Table 4.9). Its concentration ranged from $-2.87\times10^{0} \pm 3.85\times10^{0}$ Bq/l ($-7.76\times10^{1} \pm 1.04\times10^{2}$ pCi/l) at Noya Tank (NOY) to $1.02\times10^{2} \pm 1.57\times10^{1}$ Bq/l ($2.76\times10^{3} \pm 4.54\times10^{2}$ pCi/l) at PCN. Cobalt-60, ^{137}Cs, and ^{90}Sr were not detected in the samples.

Table 4.8 - Americium and Plutonium Concentrations (Bq/l) in Surface Water Near the WIPP Site. See Appendix B for the sampling locations.

	[RN][a]	2 × TPU[b]	MDC[c]	[RN]	2 × TPU	MDC	[RN]	2 × TPU	MDC
Location	^{241}Am			^{238}Pu			$^{239+240}Pu$		
BRA	2.41×10^{-4}	5.92×10^{-4}	1.12×10^{-3}	1.05×10^{-4}	2.11×10^{-4}	2.84×10^{-4}	1.05×10^{-4}	2.10×10^{-4}	2.84×10^{-4}
CBD	1.13×10^{-4}	2.26×10^{-4}	3.05×10^{-4}	0.00×10^{0}	0.00×10^{0}	8.25×10^{-4}	0.00×10^{0}	0.00×10^{0}	3.03×10^{-4}
FWT	2.21×10^{-4}	7.66×10^{-4}	1.62×10^{-3}	0.00×10^{0}	0.00×10^{0}	9.25×10^{-4}	1.26×10^{-4}	2.52×10^{-4}	3.41×10^{-4}
HIL	-1.18×10^{-4}	2.38×10^{-4}	8.73×10^{-4}	2.11×10^{-4}	3.00×10^{-4}	2.86×10^{-4}	3.16×10^{-4}	5.59×10^{-4}	9.81×10^{-4}
IDN	3.05×10^{-4}	7.47×10^{-4}	1.42×10^{-4}	0.00×10^{0}	0.00×10^{0}	7.59×10^{-4}	4.11×10^{-4}	4.18×10^{-4}	2.79×10^{-4}
NOY	4.81×10^{-4}	5.92×10^{-4}	8.84×10^{-4}	1.37×10^{-4}	2.74×10^{-4}	3.70×10^{-4}	4.11×10^{-5}	6.14×10^{-4}	1.01×10^{-3}
PCN	3.81×10^{-4}	4.44×10^{-4}	3.44×10^{-4}	-1.05×10^{-4}	2.12×10^{-4}	7.77×10^{-4}	0.00×10^{0}	0.00×10^{0}	2.86×10^{-4}
SWL	6.51×10^{-4}	6.62×10^{-4}	4.40×10^{-4}	2.56×10^{-4}	3.64×10^{-4}	3.46×10^{-4}	0.00×10^{0}	0.00×10^{0}	3.46×10^{-4}
TUT	1.22×10^{-4}	5.48×10^{-4}	1.14×10^{-3}	2.13×10^{-4}	3.03×10^{-4}	2.88×10^{-4}	1.06×10^{-4}	2.13×10^{-4}	2.88×10^{-4}
UPR	0.00×10^{0}	0.00×10^{0}	1.25×10^{-3}	3.64×10^{-4}	4.26×10^{-4}	3.28×10^{-4}	1.21×10^{-4}	4.22×10^{-4}	8.92×10^{-4}

[a] [RN] = Radionuclide concentration
[b] Total propagated uncertainty
[c] Minimum detectable concentration

Table 4.9 - Selected Radionuclide Concentrations (Bq/l) in Surface Water near the WIPP Site. See Appendix B for the sampling locations.

Location	[RN][a]	2 × TPU[b]	MDC[c]	[RN]	2 × TPU	MDC
	^{137}Cs			^{60}Co		
BRA	1.21×10^{-1}	4.51×10^{-1}	5.07×10^{-1}	4.66×10^{-1}	4.51×10^{-1}	5.37×10^{-1}
CBD	3.23×10^{-1}	3.15×10^{-1}	3.74×10^{-1}	-9.88×10^{-3}	3.17×10^{-1}	3.74×10^{-1}
FWT	-8.33×10^{-1}	5.11×10^{-1}	4.92×10^{-1}	3.05×10^{-2}	4.44×10^{-1}	5.07×10^{-1}
HIL	2.05×10^{-1}	2.13×10^{-1}	2.65×10^{-1}	7.18×10^{-2}	2.79×10^{-1}	3.26×10^{-1}
IDN	2.03×10^{-1}	3.25×10^{-1}	3.77×10^{-1}	7.55×10^{-3}	3.44×10^{-1}	4.07×10^{-1}
NOY	1.99×10^{-2}	3.23×10^{-1}	3.66×10^{-1}	2.16×10^{-2}	3.37×10^{-1}	4.00×10^{-1}
PCN	2.54×10^{-1}	5.29×10^{-1}	6.18×10^{-1}	-2.43×10^{-1}	5.66×10^{-1}	5.92×10^{-1}
SWL	-4.29×10^{-2}	2.23×10^{-1}	2.58×10^{-1}	-1.47×10^{-1}	3.00×10^{-1}	3.19×10^{-1}
TUT	-4.59×10^{-1}	4.88×10^{-1}	5.00×10^{-1}	-3.06×10^{-1}	4.77×10^{-1}	5.11×10^{-1}
UPR	7.40×10^{-2}	2.13×10^{-1}	2.56×10^{-1}	1.74×10^{-1}	2.92×10^{-1}	3.50×10^{-1}
	^{90}Sr			^{40}K		
BRA	-1.90×10^{-2}	3.74×10^{-2}	6.29×10^{-2}	7.36×10^{0}	4.37×10^{0}	5.22×10^{0}
CBD	2.95×10^{-3}	4.00×10^{-2}	6.55×10^{-2}	4.29×10^{0}	3.20×10^{0}	4.22×10^{0}
FWT	1.19×10^{-2}	3.62×10^{-2}	6.03×10^{-2}	4.81×10^{0}	2.22×10^{0}	3.13×10^{0}
HIL	2.32×10^{-2}	3.42×10^{-2}	5.62×10^{-2}	3.92×10^{0}	2.75×10^{0}	3.52×10^{0}
IDN	-1.84×10^{-2}	4.14×10^{-2}	6.96×10^{-2}	-1.24×10^{0}	3.74×10^{0}	4.07×10^{0}
NOY	3.54×10^{-2}	4.14×10^{-2}	6.55×10^{-2}	-2.87×10^{0}	3.85×10^{0}	3.92×10^{0}
PCN	1.40×10^{-2}	4.51×10^{-2}	7.36×10^{-2}	1.02×10^{2}	1.57×10^{1}	1.10×10^{1}
SWL	-2.67×10^{-2}	4.40×10^{-2}	7.51×10^{-2}	2.19×10^{1}	4.81×10^{0}	4.81×10^{0}
TUT	4.81×10^{-3}	4.14×10^{-2}	6.77×10^{-2}	5.66×10^{0}	2.45×10^{0}	3.41×10^{0}
UPR	-1.63×10^{-2}	3.33×10^{-2}	5.77×10^{-2}	3.20×10^{0}	2.68×10^{0}	3.40×10^{0}

[a] [RN] = Radionuclide concentration
[b] Total propagated uncertainty
[c] Minimum detectable concentration

Duplicate samples were collected from two locations (Indian Tank [IDN] and TUT) to check the reproducibility of the sampling and the measurement techniques (Table 4.10). The RER values for ^{241}Am, plutonium, and the uranium isotopes in these samples were all less than one, indicating no difference between duplicate samples.

Table 4.10 - Results of Duplicate Surface Water Sample Analysis. Units are Bq/l. See Appendix B for the sampling locations.

Location	[RN][a]	2×TPU[b]	MDC[c]	RER[d]	[RN]	2×TPU	MDC	RER
	^{241}Am				^{238}Pu			
IDN	3.05×10^{-4}	7.47×10^{-4}	1.42×10^{-4}	0.050	0.00×10^{0}	0.00×10^{0}	7.59×10^{-4}	0.500
IDN Dup.	2.63×10^{-4}	3.74×10^{-4}	3.57×10^{-4}		1.96×10^{-4}	3.92×10^{-4}	5.29×10^{-4}	
TUT	1.22×10^{-4}	5.48×10^{-4}	1.14×10^{-3}	0.495	2.13×10^{-4}	3.03×10^{-4}	2.88×10^{-4}	0.407
TUT Dup.	4.85×10^{-4}	4.88×10^{-4}	3.28×10^{-4}		5.62×10^{-4}	8.03×10^{-4}	7.62×10^{-4}	
	$^{239+240}$Pu				^{234}U			
IDN	4.11×10^{-4}	4.18×10^{-4}	2.79×10^{-4}	0.983	1.21×10^{-2}	3.00×10^{-3}	7.99×10^{-4}	0.355
IDN Dup.	0.00×10^{0}	0.00×10^{0}	5.29×10^{-4}		1.37×10^{-2}	3.36×10^{-3}	3.16×10^{-4}	
TUT	1.06×10^{-4}	2.13×10^{-4}	2.88×10^{-4}	0.288	9.66×10^{-3}	2.49×10^{-3}	2.76×10^{-4}	0.818
TUT Dup.	2.80×10^{-4}	5.66×10^{-4}	7.62×10^{-4}		1.45×10^{-2}	5.37×10^{-3}	8.55×10^{-4}	
	^{235}U				^{238}U			
IDN	9.36×10^{-4}	8.14×10^{-4}	9.84×10^{-4}	0.066	1.22×10^{-2}	3.00×10^{-3}	2.92×10^{-4}	0.693
IDN Dup.	1.01×10^{-3}	7.81×10^{-4}	3.89×10^{-4}		9.40×10^{-3}	2.61×10^{-3}	8.55×10^{-4}	
TUT	5.03×10^{-4}	5.07×10^{-4}	3.40×10^{-4}	0.122	7.81×10^{-3}	2.15×10^{-3}	2.75×10^{-4}	0.704
TUT Dup.	3.89×10^{-4}	7.84×10^{-4}	1.05×10^{-3}		5.33×10^{-3}	2.86×10^{-3}	8.51×10^{-4}	

[a] [RN] = Radionuclide concentration
[b] Total propagated uncertainty
[c] Minimum detectable concentration
[d] Relative Error Ratio

4.6 Soil Samples

4.6.1 Sampling

Soil samples were collected from near the low-volume air samplers at six different locations around the WIPP site: MLR, SEC, SMR, WEE, WFF, and WSS (Figure 4.6). Samples were collected from each location in three incremental profiles: surface soil (SS, 0-2 cm [0-0.8 in.]), intermediate soil (SI, 2-5 cm [0.8-2 in.]), and deep soil (SD, 5-10 cm [2-4 in.]). Measurements of radionuclides in depth profiles provide information about their vertical movements in the soil systems.

4.6.2 Sample Preparation

Soil samples were dried at 110°C (230°F) for several hours and homogenized by grinding to small particle sizes. One gram (0.04 oz) of soil was dissolved by heating it with a mixture of nitric, hydrochloric, and hydrofluoric acids. Finally, it was heated with nitric and boric acids, and the residue was dissolved in hydrochloric acid for the determination of individual radionuclides.

4.6.3 Determination of Individual Radionuclides

Gamma-emitting radionuclides (^{40}K, ^{60}Co, and ^{137}Cs) were determined by counting an aliquot of well-homogenized ground soil samples by gamma-spectrometry. Strontium-90 was analyzed from an aliquot of the sample solution by separating it from other stable and radioactive elements using radiochemical techniques and beta